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synthesis article

Improving technology transfer through national systems of innovation: climate relevant innovation-system builders (CRIBs)

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The Technology Executive Committee (TEC) of the United Nations Framework Convention on Climate Change (UNFCCC) recently convened a workshop seeking to understand how strengthening national systems of innovation (NSIs) might help to foster the transfer of climate technologies to developing countries. This article reviews insights from the literatures on Innovation Studies and Socio-Technical Transitions to demonstrate why this focus on fostering innovation systems has potential to be more transformative as an international policy mechanism for climate technology transfer than anything the UNFCCC has considered to date. Based on insights from empirical research, the article also articulates how the existing architecture of the UNFCCC Technology Mechanism could be usefully extended by supporting the establishment of CRIBs (climate relevant innovation-system builders) in developing countries – key institutions focused on nurturing the climate-relevant innovation systems and building technological capabilities that form the bedrock of transformative, climate-compatible technological change and development.

Policy relevance
This article makes a direct contribution to current work by the TEC of the UNFCCC on enhancing enabling environments for and addressing barriers to technology development and transfer (specifically, it will contribute to Activity 4.3 of the TEC's 2014–15 rolling workplan 'Further work on enablers and barriers, taking into account the outcomes of the workshop on NSIs'). The article articulates both the conceptual basis that justifies a focus on NSIs in relation to climate technology transfer and makes concrete recommendations as to how this can be implemented under the Convention as a Party-driven extension to the existing architecture of the Technology Mechanism.

Keywords: innovation policy; technological cooperation; technological innovation; technology policy; technology transfer

1. Introduction

Climate technology development and transfer to developing countries is a key commitment under the United Nations Framework Convention on Climate Change (UNFCCC, Article 4.5) and the Kyoto Protocol (Article 10c). It will form a central pillar of any post-Kyoto Protocol deal. The key institution

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through which climate technology development and transfer is to be achieved is the Technology Mechanism (TM; see Section 3), composed of a Climate Technology Centre and Network (CTCN) and a Technology Executive Committee (TEC). Establishment of the TM in 2010 was a response to years of frustration at the failure of actions under the UNFCCC to deliver climate technology development and transfer at a scale commensurate with either commitments made by Parties to the Convention or the urgency of the problem of climate change. Since then, the TEC has initiated a rolling workplan engaging with various climate technology-related issues.

On 13–14 October 2014, the TEC convened a workshop on ‘Strengthening national systems of innovation in developing countries’. This signalled a new focus by the TEC, and was the first time national systems of innovation (NSIs) have been considered as a mechanism for climate technology development and transfer under the UNFCCC. But what are NSIs, and why are they of relevance to climate technology transfer? Moreover, does the existing international climate policy architecture address NSIs? If not, in what ways might it be revised in order to do so? This article attempts to answer these questions via a review of empirically grounded theory from the Innovation Studies and Socio-Technical Transitions literatures, illustrated by examples from both the literature and the authors’ empirical research in China, India, and Kenya.

Thereby, the article makes three contributions. First, it locates the TEC’s interest in NSIs in the context of the relevant academic literature, identifying both the relevance of such a focus and the key policy considerations this implies. Second, it extends traditional NSI perspectives to incorporate insights from the Socio-Technical Transitions literature. This enables attention to the social practices that climate technologies can facilitate. It also situates policy efforts within a context where they are competing with existing regimes of policy and practice that favour conventional (climate-incompatible) technologies. Finally, the article identifies a national-level gap in the international climate policy architecture’s ability to nurture NSIs and makes recommendations for how efforts under the UNFCCC could address this.

The article proceeds from Section 2 by introducing the NSI concept and its relevance to climate technology development and transfer. Building on this, and a critique in Section 3 of the ‘hardware-finance’ instruments that have dominated international climate policy to date, Section 4 makes recommendations for strengthening the architecture of the UNFCCC’s TM, proposing institutional support in the form of CRIBs (climate relevant innovation-system builders) in developing countries. Section 5 concludes the article.

2. NSIs and climate technology development and transfer

2.1. Understanding innovation, technological change, and development

Innovation is a broad term used to describe both the process and outcome of developing and adopting technologies and techniques that are put to use in the world. A comprehensive understanding of innovation goes beyond the common assumption of inventing technologies that are new to the world: i.e. radical innovations emerging from science-intensive research and development (R&D). First, it is important to distinguish between invention and innovation. Fagerberg (2005), for example, states that invention is the first occurrence of an idea (e.g. how to harness technical principles for making a touchscreen interface), while innovation is the first implementation of that idea in practice (e.g. the first incorporation of a touchscreen into a mobile phone released on the market). Second, not all innovations are radically new technologies based on scientific R&D. As the Organisation for Economic Co-operation and Development (OECD) Oslo Manual asserts (OECD, 2005), it is also innovative when a firm is the first to introduce a new (or improved) piece of hardware – e.g. a piece of production equipment – or a new (or improved) technique – e.g. a marketing strategy. Likewise, even if other firms have already introduced new hardware or techniques, it remains innovative to a firm when it adopts these itself for the first time.

Once innovations are introduced or adopted, there often follow processes of improvement or adaptation in which each change is also an innovation. Indeed, incremental or adaptive innovations constitute much of on-going economic activity and development. Incremental changes can add up to significant improvements over time. As Barnett (1990, p. 543) observes, 'much of the increase in productivity in industrialized countries is achieved through the aggregation of myriads of minor changes to existing production processes (rather than from individual massive jumps in productivity through investment in new vintages of technology)'. And adaptive innovations are often required to ensure an innovation better 'fits' a different context – a new country, industry, firm, farm, household – either to be adopted or to perform better in that context. For example, many adaptive innovations have been made to mobile phone handsets in Kenya. Foster and Heeks (2013, p. 343) describe the innovation responses of Chinese mobile handset firms for modifications to handsets, following suggestions from intermediaries working close to low-income consumers, in which innovations included 'dual sim card phones (allowing users to choose the lower-cost network to phone particular contacts), translation of the phone interface into Swahili, and addition of a single-button-enabled new interface for the popular M-Pesa mobile money service'.

It should be clear, therefore, that a wide spectrum of outcomes can be described as innovations. When focusing on firms, innovations can emerge in products (goods and services), processes, marketing methods, organizational arrangements, and management of external relations (OECD, 2005). Furthermore, innovations can range from the incremental to the highly novel. In terms of day-to-day economic activity, incremental forms of innovation are the most important, even in OECD countries. In many developing-country contexts, adaptive innovation is of central importance. For example, incremental innovations characterized efficiency improvements in the Korean steel industry, eventually moving to the international technology frontier (D'Costa, 1998; Gallagher, 2006), while adaptive innovation of the internal combustion engine facilitated Brazil's international leadership in transport-related biofuels (Lehtonen, 2011). This could apply, too, in the context of farmers in Sudan adapting water-efficient farming techniques to their specific environmental conditions, which is illustrative of the observation made in the United Nations Development Programme (UNDP, 2010) Technology Needs Assessment (TNA) handbook that priority technologies may need to be adapted to specific climatic conditions.

Of course, all countries aspire to creating radical innovations, as these should bring higher value-added economic returns. Certainly, there are countries that have achieved these goals in recent history, despite beginning their development pathways in extreme impoverishment. However, these pathways began with laying foundational capabilities first – incremental innovation capabilities in basic engineering and managerial competence. Alongside these, they focused on building and strengthening their innovation systems. As they did so, they could absorb more complex technologies and further develop these indigenously. In time, this meant more attention to higher-technology R&D, often in collaboration with international firms, and subsequent positions at the 'frontiers' of certain technologies. Those countries that attempted to develop their R&D capabilities first were generally unsuccessful, delaying their 'catching up' – an observation also noted by UNDP (2010).

From the perspective of climate technology development and transfer to developing countries, the above discussion tells us that innovation is not the preserve of advanced developing economies. Rather, it is a crucial part of technological change and development in all developing countries. For some countries in some climate technologies, innovation will involve the adoption of existing technologies, new adaptations of them, and the creation of new markets. An example is the success of the Kenyan off-grid solar photovoltaics (PV) market. As Byrne et al. (2014) demonstrate, although the hardware itself is mainly imported from overseas, the solar PV market in Kenya is characterized by various innovative activities, many of which have been driven by the activities of key actors (including the private sector, donors, and NGOs) over several decades, creating the conditions for the market's current success. This contrasts with the activities observers conventionally associate with 'innovation' around climate technologies, such as advances by Chinese wind power companies (Lewis, 2013) or Indian solar PV manufacturers (Ockwell, Haum, Mallett, & Watson, 2010).

2.2. Innovation and technological change: NSIs in climate-compatible development

So, innovation is just as relevant to low-income countries as it is to industrialized or rapidly emerging economies. More importantly, the Innovation Studies literature has demonstrated how innovation, technological change and economic development are all intricately linked processes. Technological change is the result of multiple processes of innovation (understood broadly). It relies on processes of learning and the accumulation of knowledge, which drive processes of economic development. It is through this focus on knowledge accumulation that Innovation Studies has been able to explain national differences in patterns of economic development, despite the globalization of the capitalist economy (Cassiolato, Lastres, & Maciel, 2003). For climate-compatible development, therefore, processes of technological change focused around climate technologies become of central relevance. Moreover, understanding how to nurture these processes becomes a key focus of enquiry. It is here that the role of NSIs comes to the fore.

Empirical analyses in the Innovation Studies literature have demonstrated that national differences in the nature, speed and extent of technological change can be explained through a systemic understanding of the national context within which technological change occurs. Each NSI provides that context. Many different definitions exist of NSIs, but the term is often associated with the work of authors such as Freeman and Lundvall (e.g. Freeman, 1997; Lundvall, 1992). More recently, authors in the climate policy field have extended this work to focus on NSIs and technological capability building as ways in which climate technology development and transfer has and can be achieved (see, e.g., Dai & Xue, 2014; Hansen & Ockwell, 2014; Ockwell & Mallett, 2012; Rennkamp & Boyd, 2013; Sagar, Bremner, & Grubb, 2009; Tawney, Miller, & Bazilian, 2013; Watson, Byrne, Ockwell, & Stua, 2014).

An NSI refers to the network of actors (e.g. firms, universities, research institutes, government departments, NGOs) within which technology development, transfer, and uptake occurs, the strength and nature of the relationships between those actors, and the institutional environment within which they operate. Note that in this definition of an NSI, 'the institutional environment' forms a central part of the context within which the network of actors operates, as does the 'strength and nature of relationships between those actors'. This is an important observation for climate policy as it provides a focus for policy intervention. Furthermore, it is possible for policy to intervene to create new, or enhance the activities of existing, actors within specific NSIs – actors who could influence the institutional environment to favour climate technologies over conventional technologies or link up disparate actors with climate technology interests.

The NSI perspective has been used to explain the success of many different countries in achieving technological change and economic development. For example, Kim (1993) uses the perspective to explain the success of the Korean semiconductor industry in achieving significant efficiency gains, OECD (1997) uses it to explain the success of technological development in OECD economies, and Byrne et al. (2014) use it to explain the success of the Kenyan PV sector. Cassiolato et al. (2003) take their analysis further, building on an NSI-based explanation of Brazil's economic success to demonstrate the relevance of an NSI perspective to explaining technological change and economic development across all developing countries, emphasizing the importance of the perspective to low-income countries. The relevance of an NSI perspective to climate-compatible development efforts is taken up by Gaast and Begg (2012). They demonstrate the centrality of an NSI perspective in supporting developing countries at all levels of economic development to formulate strategic policy and planning processes that are likely to underpin climate-compatible development pathways. This builds on Gaast and Begg's earlier work with the UNDP (2010) in formulating a new approach to TNAs under the UNFCCC, an approach that is explicit in its adoption of a systemic perspective to technological change and development, drawing directly on insights from the literature on NSIs.

2.3. Technology users and social practice: insights from Socio-Technical Transitions

Building on the Innovation Studies literature to incorporate insights from anthropology, sociology, and political science, the work on Socio-Technical Transitions enables us to take our analyses beyond the focus on firms. More specifically, it facilitates consideration of the technology user. It allows us to understand innovation as a process that occurs within the context of social practices and that shapes, and is shaped by, such practices and evolving local knowledge. Examples of such local knowledge include the cultural practices around cooking that define appropriate low-carbon energy alternatives, and expectations around personal mobility. Furthermore, as well as attending to existing institutions and market structures (e.g. supply chains for kerosene and subsidies intended to help the poor), a socio-technical perspective directs us to analyse how the dominant nature of such institutions creates a powerful inertia against alternatives (e.g. low-carbon energy technologies for lighting).

However, in the face of such inertia, this literature also has much to say about how change occurs. It conceptualizes dominant ways of realizing societal services as stable, incumbent socio-technical regimes, understood as the rules (knowledge base, belief systems, mission, strategic orientation), practices, and technologies shared by actors within industries. In the case of energy, for example, regimes would usually refer to fossil-dominated energy production and consumption that might change as a result of one of the following: successful management of niches of sustainable energy technologies to the extent that they compete with dominant fossil-based regimes (Kemp, Schot, & Hoogma, 1998); landscape-level changes such as the emergence of social and political demands for low-carbon energy (Geels, 2002); or the destabilization of socio-technical regimes (Turnheim & Geels, 2013). Of particular relevance from a climate policy perspective is the related literature on strategic niche management (SNM, niche theory), which focuses on the first of these processes of change.

Having emerged from research within industrialized-country contexts, SNM has, in recent years, begun to be applied in developing-country contexts. For example, see the special edition of *Environmental Science & Policy* introduced by Berkhout et al. (2010) for its application in developing Asia, and see Byrne (2011) and Byrne et al. (2014) for its application in Kenya and Tanzania. These articles use niche theory to understand the dynamics of how novel technologies were tested in real-world settings, and whether or not they resulted in wider use and further development. A key feature of SNM is that it directs our attention to the co-evolution of actors' expectations about a technology in the future; their learning as they experiment with that technology in real-world settings; the networks of other actors they develop; and the extent to which various socio-technical practices relevant to that particular technology become embedded in society. These co-evolutionary dynamics are assumed to happen in what amounts to a protective space – the niche – in which the normal pressures of market forces and technical performance are weakened, enabling essential learning to take place (Smith, Kern, Raven, & Verhees, 2014). Of course, these dynamics unfold within a broader context, which is conceived as consisting of the various regimes (as noted above) and a wider 'landscape' (difficult-to-influence changes such as demographics, events such as wars, etc.) (Romijn, Raven, & de Visser, 2010). Over time, niches can influence regimes, and even replace them entirely.

Understanding how and where niches have been successful and unsuccessful in influencing regimes can therefore suggest how policy might intervene to nurture climate technology niches. A policy might aim, for example, to widen and deepen access to climate technologies to benefit poor and marginalized groups and do this by nurturing new niches of climate technology applications amongst poor communities and households. Importantly, SNM emphasizes the role that key actors – 'innovation system builders' (Byrne et al., 2014) – can play in developing a niche, raising potential for policy makers and other actors (e.g. NGOs or private companies) to emulate the actions of past successful innovation system builders to achieve wider impacts and broader uptake of climate technologies and innovations.

2.4. Broadening our definition of NSIs

For most developing countries – and certainly for the least developed – only weak or highly fragmented NSIs currently exist. Consequently, although they may be implementing some projects through instruments such as the Global Environment Facility (GEF), they find it difficult to attract projects through instruments such as the Clean Development Mechanism (CDM). Even where some are now implementing CDM projects, it is not clear that they are able to leverage further development benefits. For example, Kenya has attracted CDM projects to replace incandescent lamps with energy-efficient compact fluorescents, but there appears to have been no attempt to move beyond the adoption of these to some kind of assembly activities that might nurture higher value-added capabilities (Byrne, 2013). This perhaps reflects weak policy-related capabilities as well as a lack of appropriate existing industrial activities that might be exploited to move into such production. Whatever the case, it may represent a missed opportunity.

While the traditional Innovation Studies literature demonstrates the importance of innovation systems for achieving technology-related economic development goals, the socio-technical transitions literature shows the need to be cognizant of more than the skills of, and relationships between, industrial actors. This is particularly so when creating entirely new technological or innovation trajectories that challenge the power of established technological systems (or socio-technical regimes). From this perspective we can understand that cultures of practice are as much part of the inertia of these established systems as the hard technologies and the actors who benefit from them. For example, attempts to address any of the problems associated with the use of cars for personal mobility, such as raising the price of fuel or city-centre parking fees, are met with fierce resistance from consumers as much as from producers. In other words, the interconnectedness and interdependencies that are needed for a well-functioning NSI can also facilitate inertia in that system. Geels (2002) gives an indication of the interconnections that constitute such a system (or socio-technical regime – see Figure 1). However, this diagram could just as easily represent certain aspects of a 'good' NSI.

This points us to the need to develop NSIs carefully so that they are more likely to be sustainable, particularly if we are interested in climate-compatible development and its huge uncertainties. SNM offers particular hope here. Although niche analyses often concern themselves with radically new or highly novel innovations, niche activities consist primarily of incremental learning in real-world settings. As such, there is the chance that all the groups represented in Geels' (2002) socio-technical

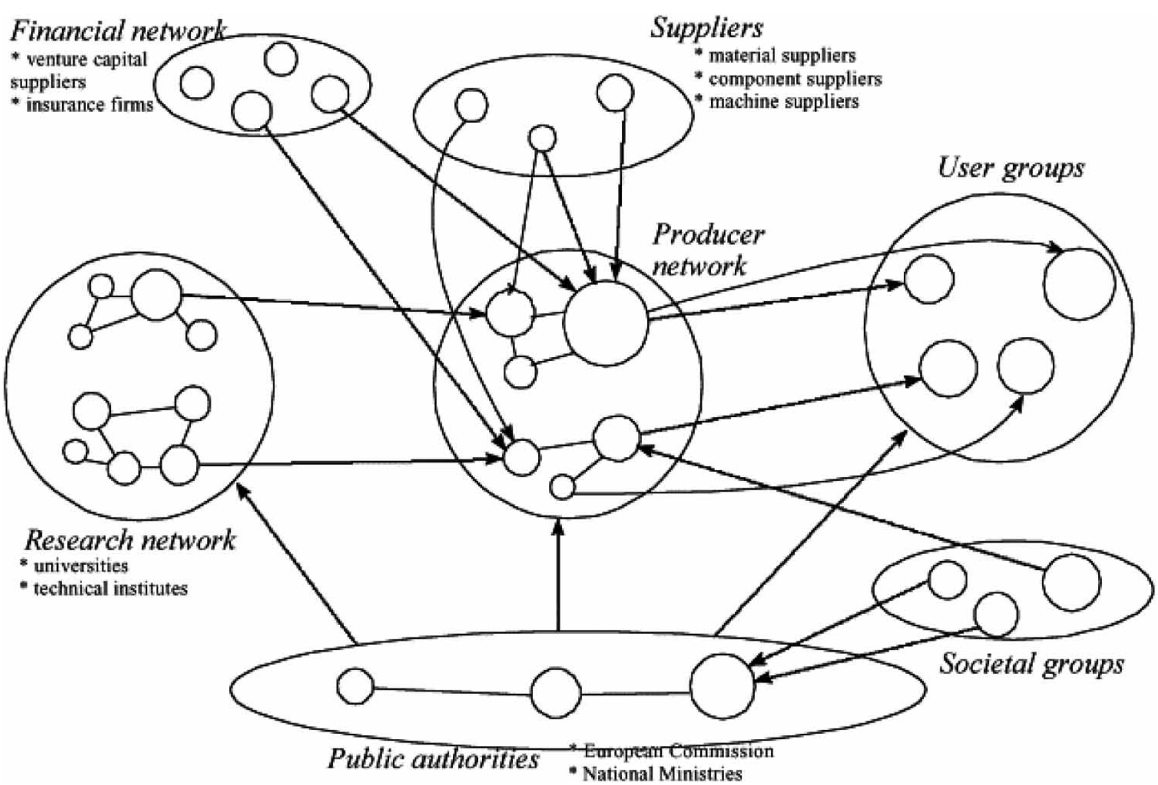

Figure 1 The multi-actor network involved in socio-technical regimes
Source: Geels (2002, p. 1260).

configuration, if brought together for 'problem-solving' in particular contexts, can develop workable 'solutions' (innovations) in a co-evolutionary process that meets their differing needs. SNM identifies four sets of generic activities – or processes – that should be pursued in order to develop such innovations:

- Learning and creating knowledge
- Institutionalizing learned socio-technical practices
- Growing and developing constituencies of support
- Consensus-building

These activities fit well with what we know about NSIs from the Innovation Studies literature and what we understand about how to nurture their development. Learning and creating knowledge about particular innovations relates to building capabilities and is crucial for the continued development of an innovation system that is creative and adaptive. Such learning needs to be fostered on the many dimensions of an innovation: not just the technical and economic, but also in terms of relevant user preferences and practices, government policies, and the infrastructure in which the innovation is to be used. Institutionalizing learned socio-technical practices is the process by which the capabilities developed during learning are widely adopted. It also refers to the development and instigation of relevant policies, laws, and regulations, as well as less formal 'rules' such as cultural norms. Growing and developing constituencies of support refers to encouraging the growth of networks of actors who invest various resources (financial, knowledge, political, etc.) to help realize the success of the innovation. These actor networks can form the basis on which the linkages and feedbacks necessary for detailed understanding of societal and market needs can be built, as well as enhancing the general flow of knowledge resulting from learning. They also help in consensus-building by providing the channels through which expectations about the innovation and its role in 'solving' particular societal needs can be discussed, negotiated, contested, etc. Furthermore, consensus-building can justify certain kinds of practice over others, providing – through institutionalization processes – the cultural norms to which firms can respond when developing specific innovations. Consensus-building can also perform more overtly political work, pressuring policy makers into designing institutional frameworks that support specific innovations. Of course, there are no guarantees of a smooth ride in these processes, but their incremental nature leaves space for adaptation to changing circumstances (whether social, technical, or environmental). Specific policy recommendations are discussed in Section 4, which translate these conceptual processes into suggested practical interventions.

To summarize, we can define in broad terms what a well-functioning NSI means. Based on the literatures discussed above, an NSI is made up of 'interconnected firms, (research) organisations and users all operating within [a national] institutional environment that supports the building and strengthening of skills, knowledge and experience, and further enhances the interconnectedness of such players' (Byrne, Schoots et al., 2012, p. 1). However, we extend this definition to include the socio-technical nature of innovation and the competition climate technologies face from existing socio-technical regimes. We can add to this the international dimension. That is, any well-functioning NSI will also be connected internationally through market, social, and political relationships and, indeed, these are essential for the continued flow and development of knowledge, skills, and innovations. As noted above, this kind of systemic approach is able to explain the success of many countries in effecting processes of technological change. It has also been operationalized via more practice-based interventions: for example, Practical Action's market mapping approach for driving technology development and diffusion in Africa (Albu & Griffith, 2005).

3. Limits to the UNFCCC architecture: hardware financing and information exchange

Once the insights discussed above are understood, it is possible to analyse why the mechanisms for climate technology transfer under the UNFCCC have so far met with limited success. As Pueyo, Mendiluce, Naranjo, and Lumbreras (2011) explain, the UNFCCC has used three vehicles for climate technology transfer to date: institutions (currently the TM, including the TEC and the CTCN); information-sharing (TNAs and the TT:Clear website); and financial vehicles, including the GEF and the CDM. The only vehicle with potential to deliver the kind of technological capability building emphasized above is the TM (although, as we explore below, this also has limitations in its current form). The information-sharing initiatives have seen little or no translation into actual projects or programmes (Pueyo et al., 2011), although practice around TNAs has improved significantly following the release of more recent guidelines (see UNDP, 2010), notwithstanding remaining gaps in relation to the

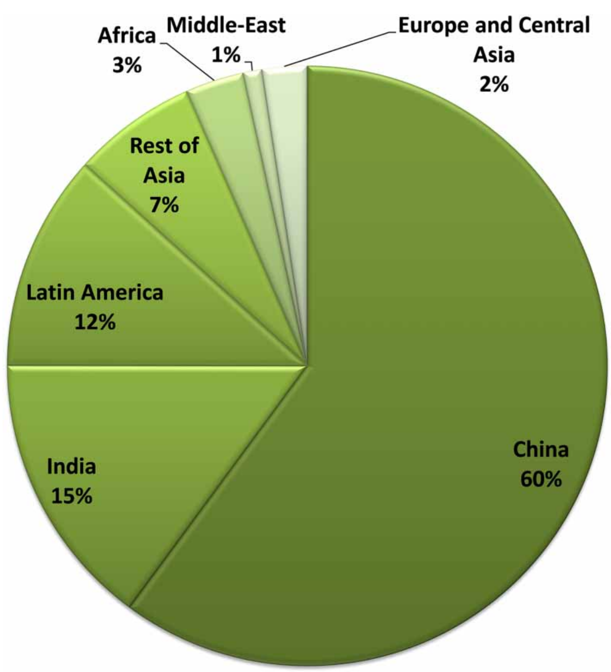

Figure 2 Distribution of cumulative investment under the CDM.
Note: Figures represent percent of total accumulated investment by the end of January 2015.
Source: Authors, based on analysis of the CDM pipeline (http://www.cdmpipeline.org).

strategic assessment of barriers and translation into implementation plans. And the financial vehicles have led to an uneven geographic spread of investment. The majority of accumulated investment from the CDM by January 2015, for example, went to China (60%) and India (15%). Africa as a whole only received 3% (see Figure 2). Little investment has gone to 'new' technologies or those likely to transform local contexts in developing countries. Instead, it has mostly gone to commercial or close-to-market technologies. By January 2015, for example, 56% of investment had gone to wind and hydro, and just 5% to solar projects (CDM pipeline http://www.cdmpipeline.org). Some might argue that the distribution of investment under the CDM has followed the distribution of global emissions, with China and India appropriately obtaining the lion's share, but Figure 3 shows this to be mistaken. The figure displays total CO_2 emissions and CDM investments for Africa and selected countries. Africa as a whole has received less than half the CDM investment per tonne of carbon emitted compared with Mexico, a third compared with China and India, and a fifth compared with Brazil.

The main problem with these financial instruments is that they are 'hardware-financing mechanisms' (Byrne, Smith, Watson, & Ockwell, 2012). They fund investment in technological hardware, neglecting whether flows of knowledge accompany the hardware investments. Without such knowledge flows, any impact on the recipient country's technological capabilities and propensity for climate-compatible development is likely to be small. Hardware-financing mechanisms are therefore unlikely to foster technological change across all developing countries. Instead, they reinforce existing

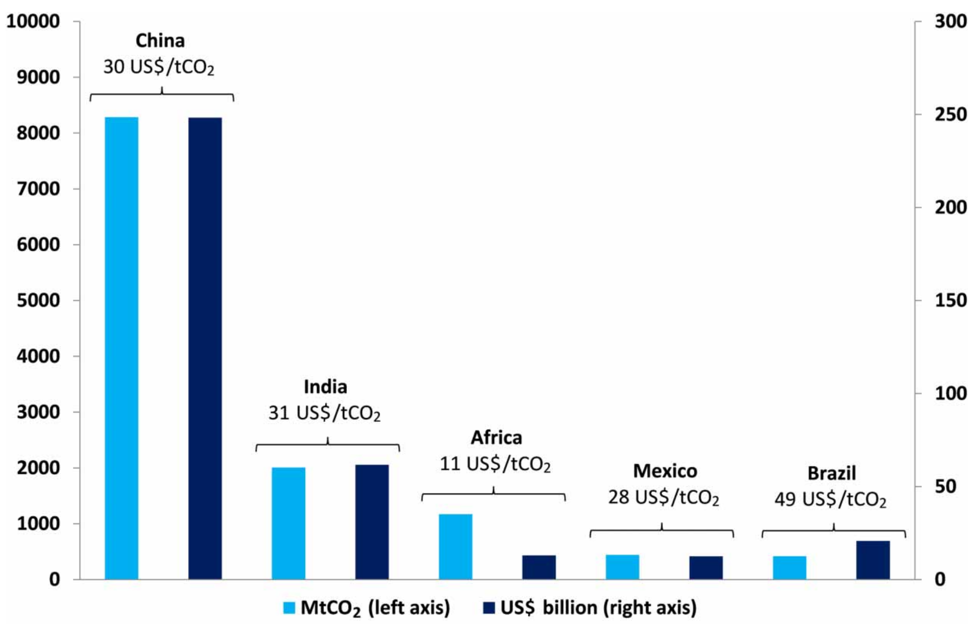

Figure 3 CO_2 emissions and CDM project investment.
Notes: Figures represent national or regional CO_2 emissions (million tonnes) and CDM investment received (in US$ billion) by the end of January 2015
Source: Authors, based on World Development Indicators and analysis of the CDM pipeline (http://www.cdmpipeline.org).

competitive advantages of those developing countries that already have strong domestic technological capabilities in specific climate technologies. Figure 2 could essentially be read as a map of the strength of existing technological capabilities in climate technologies – an assertion supported by Lema and Lema (2013) in relation to wind power under the CDM. An important means through which technological capabilities are fostered, including via obtaining international technologies and learning from interactions with international firms, is the presence of strong NSIs relevant to the technologies or sectors in question. Indeed, analysis has shown that China proactively used the CDM to strengthen its NSI and technological capabilities in key climate technology industries (Stua, 2013; Watson et al., 2014).

This is not to say that hardware-finance is unimportant – it is – but to achieve transformative change, particularly in countries with weak technological capabilities and NSIs, it is also necessary to focus on strengthening capabilities. Nevertheless, hardware-financing mechanisms have dominated policy attention under the UNFCCC, distracting attention away from other considerations necessary for achieving climate technology development and transfer (de Coninck & Sagar, 2014).

The third and final piece of the UNFCCC technology transfer architecture is the Technology Mechanism. Although it is structured in a way that has the potential to focus on strengthening NSIs, a critical gap exists at the national level. As its name suggests, the CTCN is structured around a climate technology centre, which coordinates a broader network. The Centre is hosted by United Nations Environment Programme (UNEP) in collaboration with the United Nations Industrial Development Organization (UNIDO) and support from 11 centres of excellence located in developing and industrialized countries. The CTCN's Network refers to a range of technical experts and centres of excellence with expertise that might be matched against requests from countries for technical assistance. Requests from countries come from national designated entities (NDEs). NDEs (usually government ministries or agencies[1]) are granted responsibility by Parties to the Convention to manage national technology-related requests to the CTCN. These requests are coordinated by the Centre, which responds itself to some, while others are distributed to relevant experts in the Network. This NDE-instigated approach attempts to facilitate a process that is demand-driven by Parties. There are three core services offered by the CTCN (see CTCN, 2014, for a detailed description of these services):

1. Provide technical assistance to developing countries to enhance transfer of climate technologies
2. Provide and share information and knowledge on climate technologies
3. Foster collaboration and networking of various stakeholders on climate technologies

The first core service follows requests from NDEs, while the other two services can be initiated by the CTCN or other stakeholders, as and when common needs are identified. From the perspective of building NSIs, there are several points to note with regard to the CTCN:

1. The Network is not an in-country network of actors of relevance to different climate technologies as described in Section 2.4 in relation to constituencies of support.
2. Parties can request, via NDEs, support from the CTCN in advising on and instigating the kind of climate innovation system building policies detailed in Section 4 below.
3. NDEs are usually government institutions – not locally nested, climate technology-specific institutions.

4. The CTCN's activities do not explicitly recognize the need to nurture NSIs as part of the technology transfer, development, and diffusion process, although elements of innovation system building are implicit within two of the CTCN's core services. These focus on information- and knowledge-sharing, and fostering collaboration and networking, between stakeholders.
5. Recognition of knowledge-sharing, networking, and the emphasis on capacity building elaborated in the operating manual for NDEs suggests potential for the CTCN to achieve a stronger focus on innovation system building. However, this would require explicit attention to, and understanding of, NSIs and processes for strengthening them to be integrated into the CTCN's approach. Section 4 provides details of two concrete proposals for achieving these NSI-building and strengthening processes.

4. Climate relevant innovation-system builders (CRIBs)

A final insight from empirical analyses in the Innovation Studies and Socio-Technical Transitions literatures is that key actors (individuals or institutions) can be identified who play a role in building functioning innovation systems. We refer to these key actors as 'innovation system builders', but within the literature they have variously been called 'systemic intermediaries' (van Lente, Hekkert, Smits, & van Waveren, 2003), 'intermediaries' (Howells, 2006), 'cosmopolitan actors' (Deuten, 2003), and 'technology advocates' (Rob Raven, personal communication). This variation in terms highlights a need to draw these strands of literature together into a more comprehensive theory. However, for the purposes of policy making it provides a powerful concept. Essentially, in case studies where more extensive uptake of climate technologies has been observed, key actors can be identified who undertake specific activities that contribute to the strengthening of innovation systems around those technologies. For example, Byrne et al. (2014) demonstrate this in relation to the success of the off-grid solar PV market in Kenya. There is therefore the potential for policy interventions to focus on enabling actors and institutions to act as climate relevant innovation-system builders (CRIBs).

Learning from the insights above, this requires nationally nested, demand-driven interventions that are both intra- and internationally networked, facilitating learning across different contexts in order to build indigenous technological capabilities and well-functioning, context-sensitive NSIs. At present, however, the CTCN affords little capacity at the national level. NDEs are usually contact points consisting of a small proportion of individual civil servants' jobs. They are not the kind of actor with the resources or expertise to identify others across promising areas of climate technology development or adoption in different country contexts. It is here that the support of CRIBs can add value.

It is important to note that this concept has synergies with, but differs from, existing centre-based ideas, both in the literature and in practice. A centre-based approach was suggested in at least two proposals at the time of the UNFCCC negotiations in Copenhagen in 2009. Ockwell et al. (2009) made their suggestion in a policy brief and, most notably and more substantively, Sagar et al. (2009) made theirs in a published article. Both called for the establishment of 'climate innovation centres' in developing countries, citing successes of initiatives such as the CGIAR (Cooperative Group for International Agricultural Research), the UK Carbon Trust, and institutions such as Innovacion Chile (see Ockwell, Watson et al., 2010). Significantly, the paper by Sagar et al. led to infoDev (the World Bank's innovation arm) commissioning further analysis (see Sagar, 2010), which led to the establishment of infoDev's

Climate Innovation Centres (CICs) with DFID and Danida (the UK and Danish donor agencies). However, the implementation of the CICs differs markedly in practice from that suggested by Sagar et al. (2009).

The proposal by Sagar et al. (2009, p. 280) was for 'a network of regional "Climate Innovation Centres"' that would focus on building innovation ecosystems around specific low-carbon energy technologies. This included a range of capacity building activities – activities that go well beyond what eventually became those of the infoDev-led CICs. The CICs also differ from Sagar et al.'s proposal in that they are nationally situated, not regional, but their activities are also far more limited than this. They focus on financing the activities of entrepreneurial SMEs, ignoring the activities of the multitude of other relevant actors who make up NSIs or the kinds of activities that nurture them. Even so, given their networked, international reach, the CICs represent an important initiative to engage in any attempt to foster NSIs. However, their focus on financing innovation and entrepreneurship limits them to a narrow (but nevertheless important) part of any more systemic approach to nurturing NSIs. However, climate innovation system building could be integrated into the CICs' activities under an extended remit. This may be something that infoDev and their partners in the CICs might wish to consider in the future. After all, CICs are likely to represent important networks of climate technology-relevant individuals and organizations across the public, private, and NGO sectors, and provide excellent routes for identifying and engaging with key actors.

As well as the UNFCCC's CTCN and the CICs, there are several other initiatives being launched at present with funding from the GEF via the Regional Development Banks. These include the Pilot Asia-Pacific Climate Technology Network and Finance Center led by the Asian Development Bank and UNEP; the Finance and Technology Transfer Centre for Climate Change led by the European Bank for Reconstruction and Development (EBRD); the Pilot African Climate Technology Finance Center and Network, led by the African Development Bank; and the Climate Technology Transfer Mechanisms and Networks in Latin America and the Caribbean led by the Inter-American Development Bank. These look closer to Sagar et al.'s (2009) original proposal in that they are regionally located centres. However, as with the CTCN, the extent to which these GEF-funded initiatives support the development of NSIs depends on the extent to which innovation system building can be mainstreamed across their various activities, and the extent to which their regional bases allow them to reach out to and develop detailed knowledge of national contexts. Aside from the EBRD initiative, which, like the CICs, is mostly focused on finance, the language used by these initiatives is certainly open to a systemic approach, but achieving real differences to NSIs will depend on more deliberate integration of climate innovation system building activities across the board.

It is in recognition of both the limits and potential of these existing initiatives that this article situates two proposals through which activities under the UNFCCC could be extended to focus on nurturing NSIs:

Proposal 1. Strengthen the capacity of NDEs under the CTCN by funding and supporting national-level climate relevant innovation-system builders (CRIBs) within developing countries:

1. CRIBs would play a strategic, facilitating role, linking up relevant national actors, targeting and coordinating project and programme-level interventions to maximize benefits to NSIs.
2. CRIBs (through NDEs) would coordinate with the CTCN to communicate national priorities (with due knowledge of national policy priorities and local realities).

3. The CTCN would act to network CRIBs internationally, facilitating knowledge flows and access to international technological capabilities based on a more detailed understanding of local capabilities and needs.

Proposal 2. Use climate technology projects and programmes to build climate innovation systems.

1. If pursued jointly with Proposal 1, this role can be facilitated by CRIBs, in coordination with the CTCN.
2. If pursued in isolation, this can be achieved by revising the remit of the CTCN to integrate a climate innovation system building approach into projects, programmes, and related interventions, and to provide advice, via NDEs, on how Parties can bolster their own NSIs. Under this approach, projects and programmes themselves become CRIBs.

It is important to emphasize that the success (practically and politically) of these proposals relies on them remaining country-driven and demand-led. The intention is to devolve as much agency as possible to individual countries, whilst providing international support in the form of funding and expertise. This conforms to the spirit of the Convention and to specific commitments to support climate technology transfer, development, and diffusion. Proposal 1 is the preferred option, with most potential to foster the development of NSIs around climate technologies in developing countries. Proposal 2 would be best used to augment the remit of the CTCN, mainstreaming a focus on NSIs. Proposal 2 could, however, be pursued on its own if Proposal 1 were seen as too ambitious.

There are important differences between the CRIBs proposed here and either Sagar et al.'s (2009) proposal or the other international policy initiatives indicated above. First, CRIBs are intended to operate at the national and sub-national level and link to the regional or international level. This responds to the emphasis in the literature reviewed above on national-level interventions. For example, the innovation system builders identified by Byrne et al. (2014) in Kenya's solar PV sector were nationally situated actors, most of whom were present in the country and focused on solar PV for decades. A similar knowledge of national circumstances and capacities has been observed in China's strategic use of the CDM to strengthen its own NSI (Watson et al., 2014). Most examples cited in the literature on climate change and innovation are national-level interventions: e.g. the UK's Carbon Trust, Chile's Innovacion Chile. Only the CGIAR represents a regional-level initiative, although much of its success was achieved by national-level presence via targeted interventions.

Second, CRIBs would focus on the broader definition of NSIs described in this article. This goes beyond Sagar et al.'s (2009) definition of an 'innovation ecosystem' or the definitions of NSIs within the Innovation Studies literature. Instead, it focuses on the extended understanding of innovation and socio-technical change following the integration of insights from the Socio-Technical Transitions literature and, specifically, SNM. In this way, CRIBs would engage with the firm-level analysis that characterizes the conventional NSI literature but go beyond this in two important ways. First, CRIBs would attend to the importance of technology users and the social practices for which climate technologies might be adopted. Second, they would engage in NSI-building whilst cognizant of the dominant, climate-incompatible socio-technical regimes with which climate technologies must compete in different country contexts. The emphasis within the SNM literature on four processes of activity is therefore central to the nature and activities of CRIBs proposed here, namely:

1. Build networks of diverse stakeholders who work together in projects, programmes and other interventions
2. Foster and share learning from research and experience
3. Promote the development of shared visions amongst stakeholders
4. Support diverse experimentation with technologies and practices

CRIBs would play a strategic role within countries, acting as convenors for national actor networks across the spectrum of those involved in NSIs (users, suppliers, NGOs, policy makers, etc.), championing the development of climate technology innovation systems. Their core remit would be to link together national actors around strategic, long-term, nationally defined visions (cognizant of national policy goals and local realities). They would develop detailed knowledge of national capabilities, areas where opportunities exist for rapid development and growth, and identify areas where international expertise and knowledge-sharing are required. In this way, CRIBs would support NDEs in liaising with the CTCN to facilitate targeted, nationally driven access to international expertise. CRIBs could be based within government departments, or within existing centres of expertise, or established as independent entities linked to NDEs. Ideally, however, CRIBs would not be created anew, but would instead be run through existing institutions, building on existing national capacity and expertise (e.g. universities, research organizations, or NGOs).

CRIBs would focus on interventions around specific, nationally appropriate climate technologies at specific stages of the technology development and transfer process, including:

1. Identifying national development goals that specific climate technologies can support
2. Selecting strategic sectors for climate-compatible development within countries
3. Prioritizing technologies in light of climate and development goals and championing their promotion amongst stakeholders, including networking and linking up relevant actors
4. Analysing relevant parts of NSIs in relation to these technologies in order to identify problems and solutions
5. Facilitating participatory processes to formulate action plans for specific technologies, sectors, or national strategies

In this way, CRIBs would be well-placed to contribute to other national initiatives under the UNFCCC. CRIBs would develop in-depth knowledge of national capabilities for different, nationally relevant climate technologies. They would also develop detailed knowledge of national and international opportunities for building on and strengthening these capabilities through international cooperation and the nurturing of relevant aspects of NSIs. This knowledge base would place CRIBs in a position to coordinate preparation of countries' TNAs. They would also be able to bring a systemic and nationally grounded analysis to support other national-level initiatives, including the preparation of Nationally Appropriate Mitigation Actions (NAMAs), National Adaptation Plans (NAPs), and Intended Nationally Determined Contributions (INDCs). This systemic and grounded national perspective could promote national buy-in to activities under the UNFCCC, as well as increasing the likelihood of them having more significant impacts on national climate-compatible development efforts.

The creation of CRIBs could assist in overcoming an important concern regarding the potential for the CTCN's network to become too large and unwieldy. CRIBs would bolster the capacities of NDEs, ensuring that the demand-led vision of the CTCN is meaningfully realized and that technical assistance sought via the CTCN is targeted at nationally defined priorities based on an in-depth knowledge of national capabilities and needs. Funding is envisaged via a portfolio of sources, including the Green Climate Fund, the GEF, national governments, donors, NGOs, other multilateral organizations, and the range of other international actors with an interest in funding sustainable development – and climate change mitigation and adaptation – projects and programmes.

As with the CTCN, attention is needed upfront to ensure that activities conform to the funding criteria of the GEF, the Green Climate Fund, and other potential funders. This may require tailoring and packaging of different initiatives accordingly. The added value of channelling such funding through, or at least engaging with, CRIBs is the opportunity to enhance coordination and ensure spending benefits climate-relevant aspects of NSIs via a grounded understanding of the context-specific needs of individual countries and technologies. This would provide a means of mainstreaming climate innovation system building activities within individual countries.

Ideally, Proposal 2 would be pursued in tandem with Proposal 1, with CRIBs leading the national implementation of Proposal 2 in liaison, via NDEs, with the CTCN. Should Proposal 1 be considered too ambitious or meet with resistance, however, Proposal 2 can still be implemented by extending the CTCN's remit to include NSI-building as a core aim. In the event that some Parties choose to pursue Proposal 1 while others do not, Proposal 2 is designed to work effectively within such a context and make the most of all climate technology projects and programmes that are pursued in developing countries.

5. Conclusion

The literature reviewed in this article represents the theoretical outcomes of decades of empirical research, emphasizing the role that national systems of innovation (NSIs) play in shaping technological change and economic development. As well as this, the literature's insight on the role of key actors in nurturing NSIs provides important purchase for international climate policy. It opens up the possibility of systemic interventions at the national level aimed at nurturing NSIs around climate technologies so as to support climate-compatible development pathways.

The analysis in this article broadens the firm-centric focus of the traditional NSI literature by building on insights from Socio-Technical Transitions thinking, enabling a focus on technology users and the social practices that are fulfilled using climate technologies. It situates efforts to nurture NSIs within the context of competition with existing socio-technical regimes that favour conventional, climate-incompatible technologies. By focusing on the goals of building networks, fostering shared learning and shared visions, and supporting experimentation through projects and programmes, the nationally nested climate relevant innovation-system builders (CRIBs) proposed here could fill a gap at the national level in international policy supporting climate technology development and transfer.

Both proposals (particularly Proposal 1) would support nationally driven and nationally appropriate actions and strengthen Parties' agency to foster climate technology development in ways that meet nationally determined needs and priorities. Both are therefore aligned with the Party-driven tone of the United Nations Framework Convention on Climate Change (UNFCCC). They aim to build national technological capabilities and well-functioning, context-sensitive NSIs via nationally nested, demand-driven, internationally networked activities, sharing learning across different contexts.

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Note

1. For a full list, see http://unfccc.int/ttclear/templates/render_cms_page?s=TEM_ndes.

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